Precip. Interception

INTERCEPTION of PRECIPITATION by Northern Hardwoods

by Raymond E. Leonard

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THE PROBLEM OF INTERCEPTION

WHEN forest watershed management research was begun at the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire in 1955, we felt certain that at least one aspect of hydrology would not require study—interception. Interception has been studied for a long time, in fact, as early as 1889 (Horton, 1919). It has been well known that a certain amount of rainfall or snow clings to leaves and branches and never reaches the ground.

Yet, as we began our research, a review of the literature about interception in northern hardwoods revealed that these earlier studies were too limited by either sampling or measurement techniques to provide useful information. We found that we could not estimate interception without making measurements of our own.

So we began a 2-year study of interception in 1958. During its course we determined the interception of precipitation by a northern hardwood forest, both summer and winter, and learned something of the variation of rainfall distribution within the forest stand. Since the information contained in this report will be of interest mainly to other technicians in the field, our methods and results are presented in fairly fine detail.

PREVIOUS WORK

Early investigators found that the amount and proportion of precipitation intercepted by the tree canopy varies with type of precipitation (rain or snow), storm size, and type and condition of the forest cover. Early studies were summarized by Horton (1919) and Kittredge (1948). A more recent review of the literature was presented by Delfs (1955).

Relatively little has been published about the effects of hardwood forest canopies on rainfall. Zon (1927) concluded that a broad-leaf forest intercepts about 13 percent of the rainfall annually. Mitchell (1930) reported that a hardwood-hemlock stand in northern Wisconsin withheld 25 percent of the rainfall during the leaf period and 16 percent of the rainfall during the leafless period, an average of 18 percent annually. And Trimble and Weitzman (1954) found that Appalachian hardwood can-

Figure 1. — Second-growth northern hardwood stands in the study area. Throughfall gage in place (arrow).

opies intercept approximately 25 percent of the annual gross rainfall.

But none of these studies included measurements of water running down the stems of trees. All used a fixed-gage system of sampling rather than random sampling with roving gages. And none of them covered the northern hardwood area.

In the course of previous investigations, a number of terms have been used, and will be used here, to describe the various components of the interception process. So for sake of clear understanding, some basic definitions are in order.

> *Interception.*—That part of the precipitation retained by the aerial portion of the vegetation and either absorbed by it or returned to the atmosphere by evaporation.
>
> *Gross precipitation.*—The total amount of precipitation measured in the open or above the vegetative canopy.
>
> *Throughfall.*—That portion of the precipitation that reaches the ground directly through the tree canopy.
>
> *Stemflow.*—That portion of the rainfall that, having been intercepted by the canopy, reaches the ground by running down the tree stems.
>
> *Net precipitation.*—That portion that reaches the forest floor, or the sum of throughfall and stemflow.

STUDY AREA

The area selected for this study is on a 15-percent slope with a southeastern aspect at an elevation of 1,500 feet. Average annual precipitation at the Hubbard Brook Experimental Forest is about 50 inches. Approximately 30 inches of this occurs during the growing season or leaf period; of the remainder, about 8 inches comes as snow, and 12 inches as rain. Almost one-half of the storms deposit 0.10 inch or less; only 6 percent of the storms deposit more than 1.00 inch. Average annual temperature is around 40°F., with an average January temperature of 16° and an average July temperature of 68°. Temperatures range from

50° to 90°F. during the leaf period. Winter temperatures can drop to a low of —20°F. Winds are predominantly from the west.

This area was cut over about 50 years ago. About one-half of the trees in the present stand are beech, one-third are sugar maple, and there is a scattering of yellow birch and miscellaneous species (fig. 1). The summer canopy is 85 to 98 percent closed (fig. 2).

STUDY METHODS

Interception by a forest canopy cannot be measured directly but may be arrived at by subtracting net rainfall from gross rainfall. In this investigation, net rainfall was determined by measuring its components: throughfall and stemflow.

Data were collected both summer and winter during the two years 1958 and 1959. The general procedure was to directly measure gross precipitation, throughfall, and stemflow. Interception was then computed by subtracting from gross rainfall the sum of throughfall plus stemflow.

Measurements were taken in three ½-acre plots with similar forest cover; species and stand characteristics are given in table 1. The three plots, 500 feet apart, were subdivided into 10-foot grid

Table 1.—*Tree cover on study plots*

(Projected-area basis)

Item	Plot 1	Plot 2	Plot 3	Plot Ave.
Trees . . . Number per acre . .	668	590	724	660
Basal area . . . Square feet per acre . .	143	132	129	135
Basal area by diameter class:				
1-10 inches . . . Percent . .	53	49	77	60
11+ inches . . . Percent . .	47	51	23	40
Species composition (based on number of trees):				
Beech . . . Percent . .	51	56	40	49
Sugar maple . . . Percent . .	25	18	41	29
Yellow birch . . . Percent . .	16	12	12	13
Miscellaneous . . . Percent . .	8	14	7	9

Figure 2. — Looking straight up at the tree canopy above a throughfall gage. Top: the canopy in leaf period; notice the multilayered structure, with few openings. Bottom: the same view in the leafless period.

squares. Corners of the 256 grid squares in each plot were marked with numbered metal rods.

Throughfall was caught in each plot with five standard 8-inch rain gages. The gages were placed in the center of five randomly selected grid squares. After a storm of 0.30 inch or more, as measured in the open, all throughfall gages were moved to a new set of randomly selected grids. All rain gages were placed on the ground and held upright by a stake and a wrap of wire.

Gross precipitation was determined by averaging measurements obtained in four nearby openings. Three of these contained a standard 8-inch rain gage. In the fourth opening, a recording rain gage was placed. Each opening was 150 to 200 feet in diameter, of such size that surrounding objects were no nearer than once their height from the gage.

Stemflow was measured on 37 trees in two areas located between the throughfall plots. All major tree species common to the forest were included in the two areas. Tree diameters ranged

Figure 3. — The stemflow study area. Water running down tree stems was caught by metal collars and drained through plastic tubing to collecting drums and cans.

Figure 4. — Volumetric measurement of stemflow collected in 55-gallon drum. The rate of stemflow here necessitated use of two plastic drain tubes.

from 1.0 to 14.7 inches d.b.h. One area contained 15 trees on 1/20 acre, and the other had 22 trees on 1/10 acre.

To measure stemflow, all trees were equipped with zinc collars projecting 3/4 inch from the tree trunk. The collars, preformed around a rope, were attached to the tree with small nails, and soldered in place. Junction of the collar with the tree was made watertight with asphalt roofing cement. Stemflow from the larger trees was led from the collar by a 3/4-inch plastic hose to an upright 55-gallon drum, and measured volumetrically (fig. 3 and 4). On the smaller trees stemflow was caught in 5-gallon cans and weighed with a spring scale.

Gross precipitation, throughfall, and stemflow were measured after each storm. Winter throughfall was measured by charging

each rain gage with anti-freeze and weighing the gages after each storm. A storm was defined as any period of precipitation followed by 6 hours without precipitation.

Throughfall and stemflow measurements were taken when the trees were in full leaf; we shall call this the leaf period. Throughfall measurements only were taken during the remainder of the year, in the leafless period.

RESULTS

THROUGHFALL

Throughfall measurements taken in the three ½-acre plots were subjected to a covariance analysis to determine if there were consistent and significant differences between plots. As no significant difference was found, throughfall results from the three plots were combined.

Leaf Period

During the time the trees were in leaf, throughfall measurements were taken for 34 storms ranging in size from 0.03 to 1.47 inches as measured in the control gages. For this period, throughfall amounted to 82 percent of gross rainfall. Throughfall expressed as a percentage of gross storm rainfall gave an ascending convex curve (fig. 5). The percentage of gross rainfall passing through the forest canopy as throughfall was fairly constant for storms greater than 0.80 inch.

The relationship between throughfall ($\hat{Y}$) and gross rainfall (X) for storms of various sizes is given in figure 6, following the linear regression:

$$\hat{Y} = 0.8984X - 0.030 \qquad (1)$$

with a standard error of estimate: $\pm$ 0.03 inch.

Considerable variation was noticed in catch among the five gages in each of the plots. As an example, throughfall ranging from 1.05 inches to 1.73 inches was recorded from a storm total-

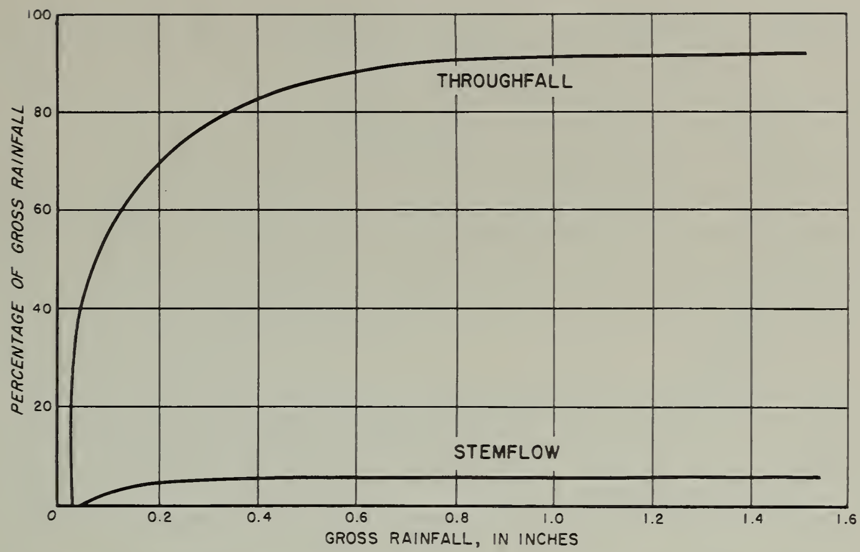

Figure 5. — Relationships between throughfall, stemflow, and gross rainfall.

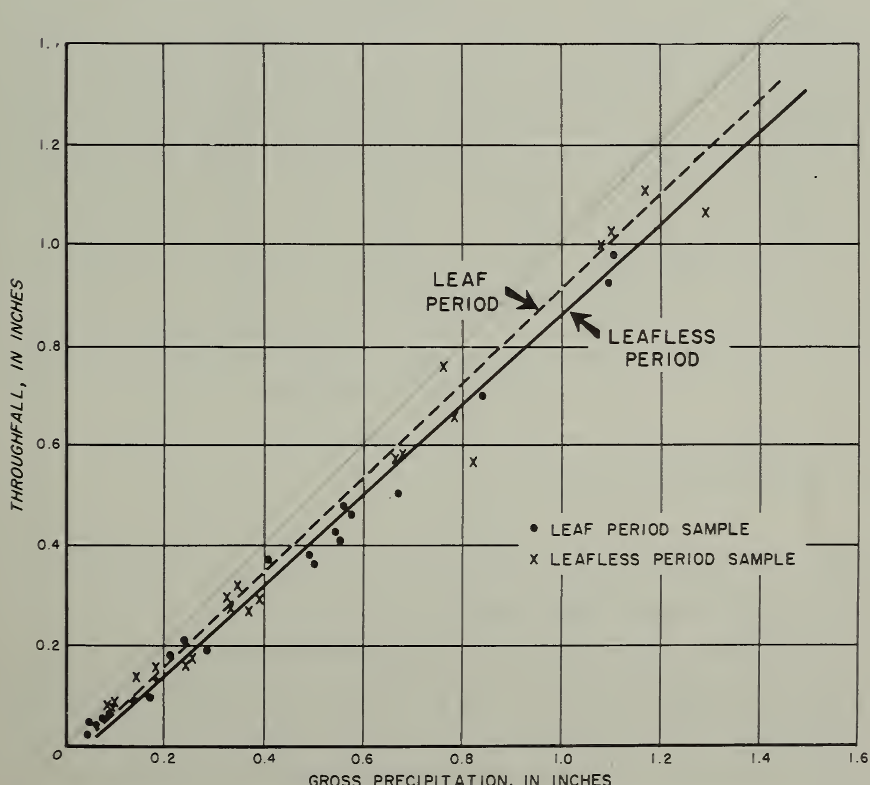

Figure 6. — The relationship between throughfall and gross rainfall.

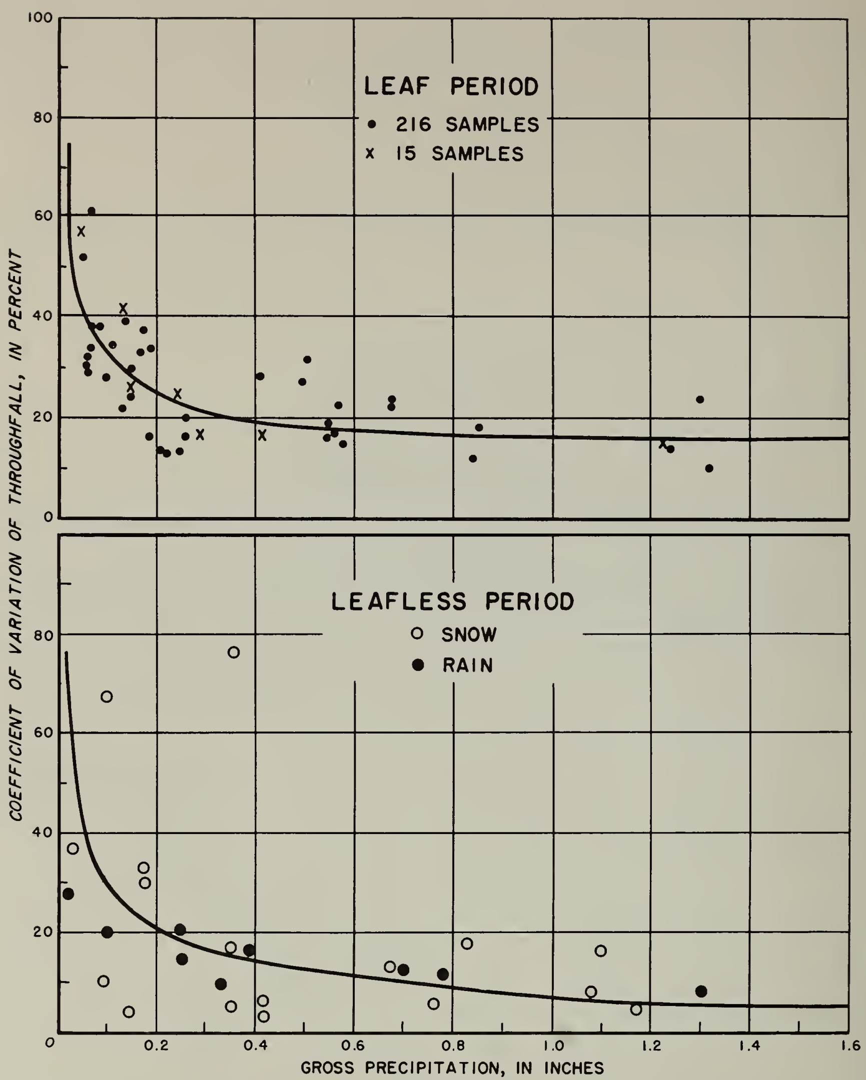

Figure 7. — The relationship of coefficient of variation of throughfall to storm size.

ing 1.47 inches of gross rainfall; and for a storm of 0.16 inch, throughfall varied from 0.06 to 0.18 inch.

Coefficients of variation of throughfall measurements are presented in figure 7. Calculations are based on mean throughfall values for the 15 measurements for each storm. It is evident from this curve that variation of throughfall around its mean varies inversely with storm size. These results point out the diminishing effect of canopy variation as storm size increases. Also, it may

be observed that throughfall variation is essentially constant throughout the forest for storms of 0.50 inch or greater.

To define this variation between throughfall measurements better, 216 one-quart cans were placed at randomly selected points in the three plots. Not only was throughfall found to be very variable from point to point, but at any particular point it was seldom consistently higher or lower than mean throughfall for the plot. Data from selected storms are presented in table 2 and plotted in figure 7.

Measurements of canopy closure were taken over each of the 216 points with spherical densiometer (Lemon, 1957) and a Weston illumination meter, model 756. Differences between

Table 2.—*Variation of throughfall, based on 216 measurements per storm*

Storm size[1] (inches)	Throughfall			Standard deviation	Coefficient of variation
	Ave.	Max.	Min.		
Inches	*Inches*	*Inches*	*Inches*		*Percent*
0.04	0.02	0.06	—	0.01	58
.12	.07	.28	0.01	.03	42
.14	.10	.16	.03	.02	25
.25	.19	.31	.08	.05	24
.28	.19	.31	.13	.03	17
.40	.33	.47	.14	.06	17
1.02	.84	1.14	.52	.13	15

[1]Based on average of 4 measurements in the open.

canopy measurements were very small and were not related to differences in throughfall measurements.

Canopy-density measurements with a densiometer or light meter resolve the total space occupied by the canopy, within a cone, into a single horizontal plane. Precipitation caught in the gage may or may not come from a cone-shaped space. Precipitation falling through a forest canopy can be influenced by a succession of obstructions on its way to the forest floor. A few twigs or even a leaf immediately above the gage may have a major influence on the amount of rain caught.

Leafless Period

Throughfall measurements were taken for 26 storms during the period when the tree canopy was bare of leaves. Storm size ranged from 0.02 inch to 1.29 inches as measured in the control gage.

Precipitation during this interval came either as rain or snow, or as a combination of both. During this period, 88 percent of the gross precipitation reached the ground under the forest canopy as throughfall.

The throughfall ($\hat{Y}$)-gross rainfall (X) regression was as follows (fig. 6):

$$\hat{Y} = 0.9424X - 0.029 \qquad (2)$$

with a standard error of estimate: $\pm$ 0.05 inch.

Coefficients of variation calculated on throughfall measurements taken during this period are presented in figure 7. It is evident from figure 7 that the coefficients of variation do not differ greatly between the leaf period and leafless period. However, it is noticeable that some of the measurements of throughfall during snow storms are rather widely dispersed around the curve.

A possible reason for this wide dispersion is that snow, particularly wet snow, clings to branches and may build up fairly large amounts in certain parts of the canopy. This may be either dropped to the ground or returned to the atmosphere by sublimation some time after the storm. In such a case, a single gage could collect either several times the amount of snow measured in a nearby gage, or only a fraction of it.

STEMFLOW

Stemflow was measured from 20 storms ranging in size from 0.07 inch to 1.47 inches. Area-inches of stemflow were computed by dividing the stemflow in cubic inches collected from the two areas by the area bounded by the vertical projection of the canopy edge.

During the period of measurements, 5 percent of the rainfall measured in the open reached the forest floor by running down the tree stems.

Stemflow expressed as a percentage of gross storm rainfall results in an ascending convex curve (fig. 5). Once rainfall reached 0.80 inch in the open, stemflow expressed as a percentage of gross rainfall tapered off and did not increase much beyond 6 percent. Rainfalls of 0.05 inch or less produced unmeasurable amounts of stemflow.

Stemflow ($\hat{Y}$) was found to be a linear function of the amount of gross rainfall (X) per storm:

$$\hat{Y} = 0.0563X - 0.0024 \quad (3)$$

with a standard error of estimate: $\pm$ 0.007 inch.

The more important factors found to affect stemflow on individual trees were: diameter, tree species, and position of the crown in relation to the plane of the surrounding forest canopy.

Stemflow expressed in cubic inches per storm for individual trees showed strong correlation with tree diameter. Cubic inches of stemflow from 15 beech trees ranging in d.b.h. from 1.0 to 10.3 inches were analyzed. Stemflow from storms of 0.28, 0.54, and 1.02 inches had coefficients of correlation with d.b.h. of 0.88, 0.91, and 0.80, respectively.

Striking differences in amounts of stemflow between species were found. Rankings in order of amounts of stemflow were: 1—American beech, 2—sugar maple, and 3—yellow birch. In all cases, the smooth-barked American beech had the greatest amount of water running down the stem. On an average, only two-thirds as much water flowed down the rough-barked sugar maple as ran down the smooth boles of the beech trees. Stemflow on the curly-barked yellow birch trees averaged about one-half the amount measured on beech trees of comparable size.

Water dripping from the ends of curly bark, branch stubs, and small limbs of yellow birch bypassed the ¾-inch wide stemflow trough. To measure this, one 10.8-inch yellow birch was fitted with a 4-inch stemflow collar placed 2 feet below a standard ¾-inch collar. Data from 11 storms showed that the 4-inch

collar caught 17 percent more water than the ¾-inch collar. Consideration should be given to wider stemflow collars on rough-barked species in future studies.

A correlation between the position of the individual tree canopy, relative to the plane of the surrounding forest canopy, and the amount of stemflow collected, was observed. It was not uncommon for a tree with a crown protruding above the surrounding forest canopy to have 30 to 50 percent more water running down its stem than a tree of the same species and similar diameter that did not stick up above the surrounding canopy.

Stemflow is not insignificant. Stemflow from a 10-inch beech for a 1.00-inch storm was equivalent to 30 gallons of water. Most of this concentrates within a distance of 1 foot, more or less, from the base of the tree (Voigt, 1960). Using this area as a basis for calculations, 30 gallons of water will result in approxi-

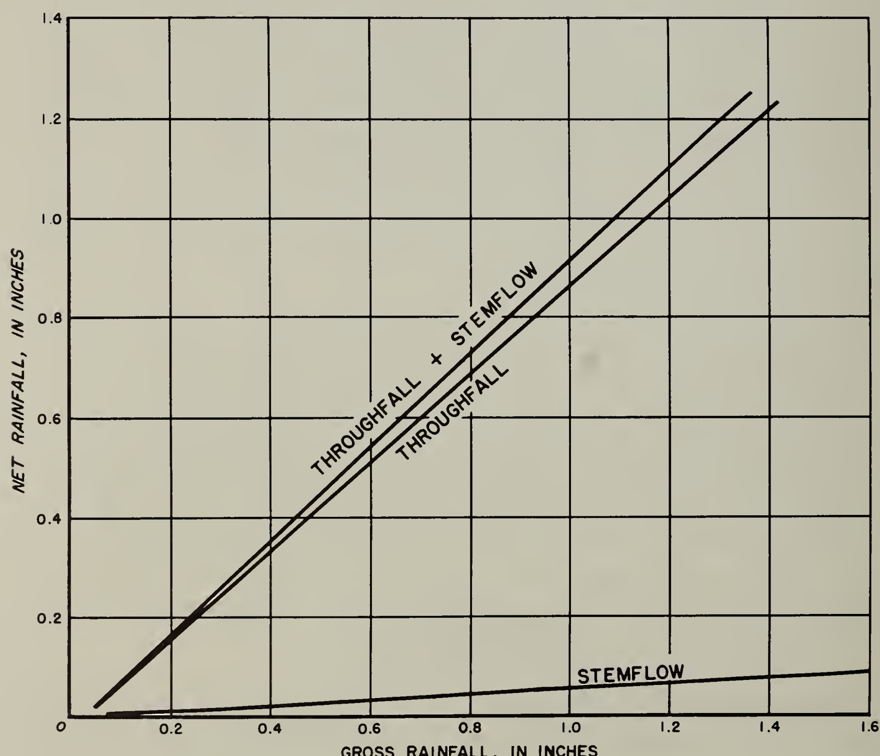

Figure 8. — The relationship between net rainfall (throughfall plus stemflow), throughfall, stemflow, and gross rainfall during the leaf period.

mately 7 inches of water at the base of the 10-inch beech tree, or 7 times the depth of gross rainfall.

Water flowing down the stem has a tendency to follow large roots into the soil (Voight, 1960). This may be facilitated by loosening of the soil by root movement when trees sway in the wind (Kostler, 1956). The addition of relatively large amounts of water to the soil beneath the tree, from stemflow, doubtless provides a supply of soil moisture for use during dry periods. The importance of this supply to the trees is evidenced by the fact that roots frequently terminate in a mass of fine rootlets surrounding and lying beneath the base of a neighboring tree (Stout, 1956).

NET PRECIPITATION

During the period of the year when the tree canopies are in leaf, throughfall and stemflow may be expressed as a linear function of the amount of rain falling in the open (fig. 8). The equation for estimating net rainfall (throughfall plus stemflow, $\hat{Y}$) from gross rainfall (X) is:

$$\hat{Y} = 0.9547X - 0.0324 \qquad (4)$$

This equation is applicable for storms greater than 0.05 inch depth. Net precipitation for smaller storms may be obtained from the throughfall equation (1).

Throughfall during the period of the year when the forest canopy is bare of leaves may be estimated by equation (2). Though there were very few stemflow data for the leafless period, stemflow amounts appeared to be similar to those measured during the leaf period. Stemflow during periods of snowfall was negligible.

Net precipitation (throughfall plus stemflow) at Hubbard Brook during the 2 years covered by this study averaged 87 percent of the gross precipitation during the leaf period. Throughfall in the leafless period for the duration of this study averaged 88 percent.

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